Effect of Soft Abdomen on Quadrupedal Gait

Hiroaki Tanaka[1], Ojiro Matsumoto[1], Takumi Kawasetsu[1], and Koh Hosoda[1]
[1]Graduate School of Engineering Science, Osaka University, Japan
tanaka.hiroaki@arl.sys.es.osaka-u.ac.jp

1 Introduction

Animals typically have a soft abdomen, whose motion significantly contributes to their locomotion. For example, a viscera inside the abdomen moves during locomotion, which improves the energy efficiency and stability of the locomotion. From these findings, some researchers have attempted to develop legged robots with soft abdomens. Although these robots could perform exceptionally well in terms of locomotion, such as being energy-efficient [1] and generating human-like ground reaction force [2], how the abdomen dynamics affect quadrupedal gait remains poorly understood.

We have developed a quadruped robot with a soft abdomen [3]. However, the model for analyzing the dynamics of the robot was simplified. For example, it only considered vertical dynamics and body posture, not horizontal dynamics. This study introduces a mechanical model that considers the horizontal dynamics of a quadruped robot with a soft abdomen. Then, we conducted a preliminary investigation into the abdomen's impact on its gait.

2 Mechanical Model

Figure 1 illustrates an abdomen of a quadruped animal. Inside the animal's abdomen, there is a soft but heavy viscera covered by abdominal oblique muscles. These muscles are classified as internal and external oblique muscles which are crossed [4]. Here, in this study, we modeled these viscera and muscles as shown in Fig. 2. The point mass represents the mass of the viscera, and its motion is constrained horizontally. Two springs imitating abdominal oblique muscles are arranged antagonistically around the mass. Thus, these two springs exert force in the trunk. The spring constant and damping coefficient of these springs are k^{ab} and b^{ab}, respectively.

We modeled a trunk and fore and hind legs in the sagittal plane because we restricted our attention to the bounding gait where the fore and hind pairs of legs act in parallel. Each leg has 2 joints: shoulder and elbow joints in the fore leg, and hip and knee joints in the hind leg. These joints are controlled such that the foot follow the elliptical trajectory. To determine the foot trajectory, we determine the phase of each leg as follows:

$$\phi_F = \omega t, \tag{1}$$

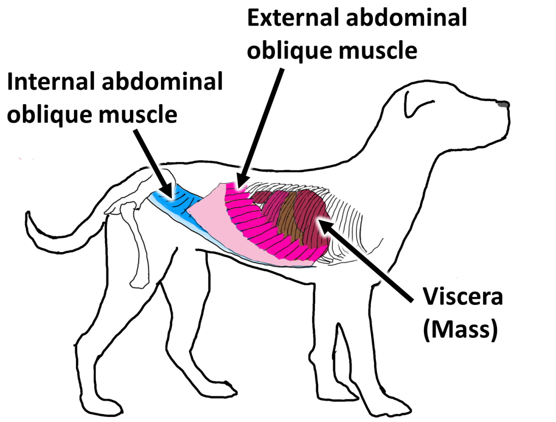

Figure 1: Abdomen of quadruped animal.

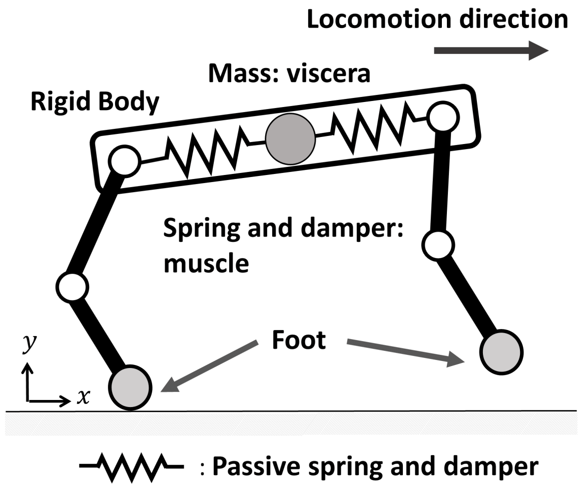

Figure 2: Quadruped model with soft abdomen

$$\phi_H = \omega t + \pi, \tag{2}$$

where ϕ_F and ϕ_H are the phase of the fore and hind legs, respectively, ω is the angular frequency of the locomotion, and t is time. Note that the phase difference between ϕ_F and ϕ_H is π [rad] such that the quadruped robot realizes a bounding gait.

3 Result

Our research attention is how the soft abdomen affects horizontal dynamics of a quadrupedal robot. Therefore, we

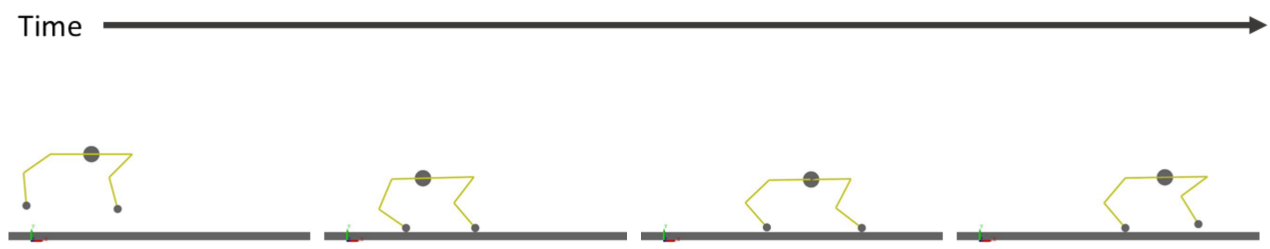

Figure 3: Snapshot of the robot running every 500.0 [ms] with $k^{ab} = 1.0 \times 10^2$ [N/m].

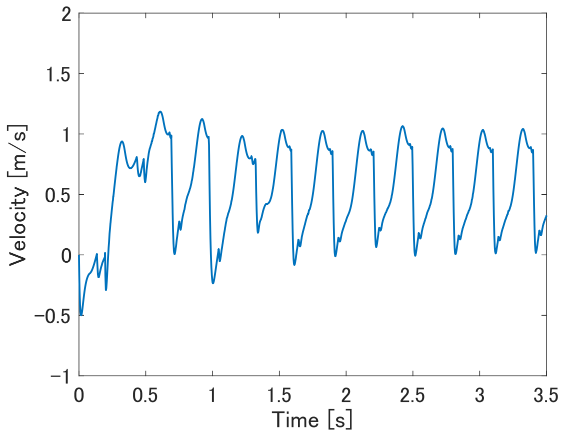

Figure 4: Time series data of velocity with $k^{ab} = 1.0 \times 10^2$ [N/m].

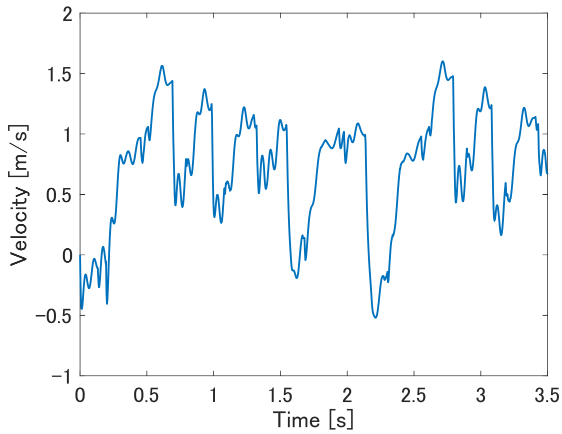

Figure 5: Time series data of velocity with $k^{ab} = 1.0 \times 10^4$ [N/m].

investigated walking speed affected by horizontal dynamics. Figure 3 represents a snapshot of the robot running, and Fig. 4 and Fig. 5 show the time series data with $k^{ab} = 1.0 \times 10^2, 1.0 \times 10^4$ [N/m]. When the stiffness of the abdomen oblique muscles were soft like $k^{ab} = 1.0 \times 10^2$ [N/m], the velocity is periodically stable. On the other hand, when the abdomen oblique muscles were very stiff like $k^{ab} = 1.0 \times 10^4$ [N/m], the velocity is periodically unstable.

4 Discussion

Based on these results, we considered that a soft abdomen is effective for achieving a stable bounding gait. Traditionally, many researchers have focused on a spine structure so that a quadruped robot realized bounding gait [5]. This is because high-speed running animals, such as cheetahs, are thought to realize bounding gait by utilizing their spine. On the other hand, our results suggest a soft abdomen design is also a key factor for realizing bounding gait. Although this report only examined a limited set of abdominal parameters and locomotion frequency, a broader range of parameters will be further investigated.

References

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